



University of St.Gallen

Wi-Fi Sensing and Privacy

Uses and Misuses of CSI and Beamforming Feedback

Bruno Rodrigues

Sensing Group (SG)
Institute of Computer Science in Vorarlberg (ICV)
School of Computer Science (SCS)
University of St. Gallen (HSG)

From insight to impact

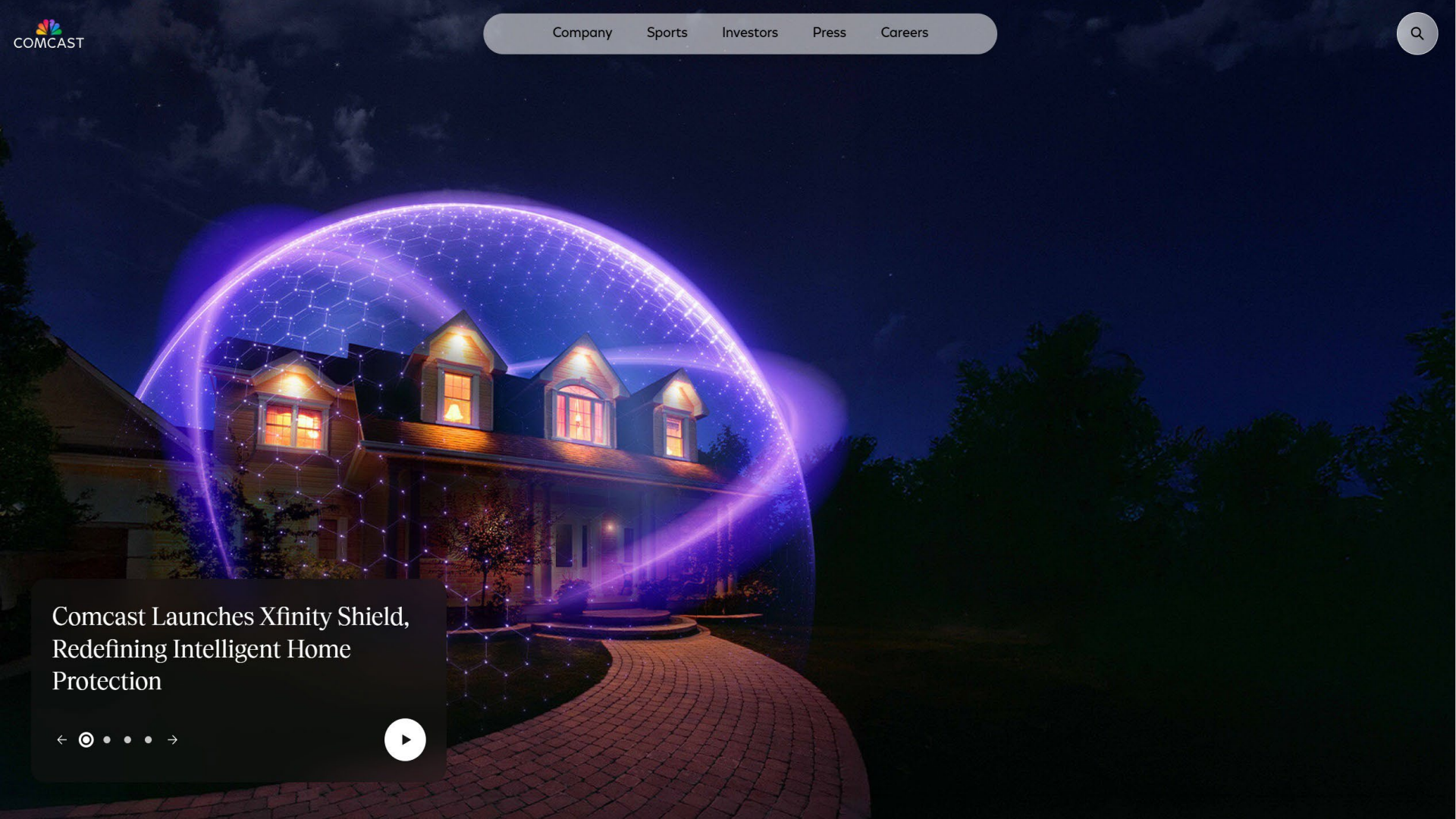


Router capability over Wi-Fi generations

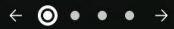
	Wi-Fi 4 2009	Wi-Fi 5 2013	Wi-Fi 6 2021	Wi-Fi 7 2024
				
antennas (streams)	4	8	8	16
channel width	40 MHz	160 MHz	160 MHz	320 MHz
modulation	64-QAM	256-QAM	1024-QAM	4096-QAM
frequency slices	56 per 20 MHz	56 per 20 MHz	242 per 20 MHz	242 per 20 MHz

**Have you noticed your router growing?
What does all that radio do when nobody is streaming?**

Maximum values: IEEE 802.11n-2009, ac-2013, ax-2021, be-2024. Slices: OFDM subcarriers in 20 MHz.



Comcast Launches Xfinity Shield,
Redefining Intelligent Home
Protection



Already in use: motion sensing in millions of routers



The Verge, 18 August 2026

Comcast's terms, as quoted in August:

"may disclose ... to third parties **without further notice to you**"

Support page, October:

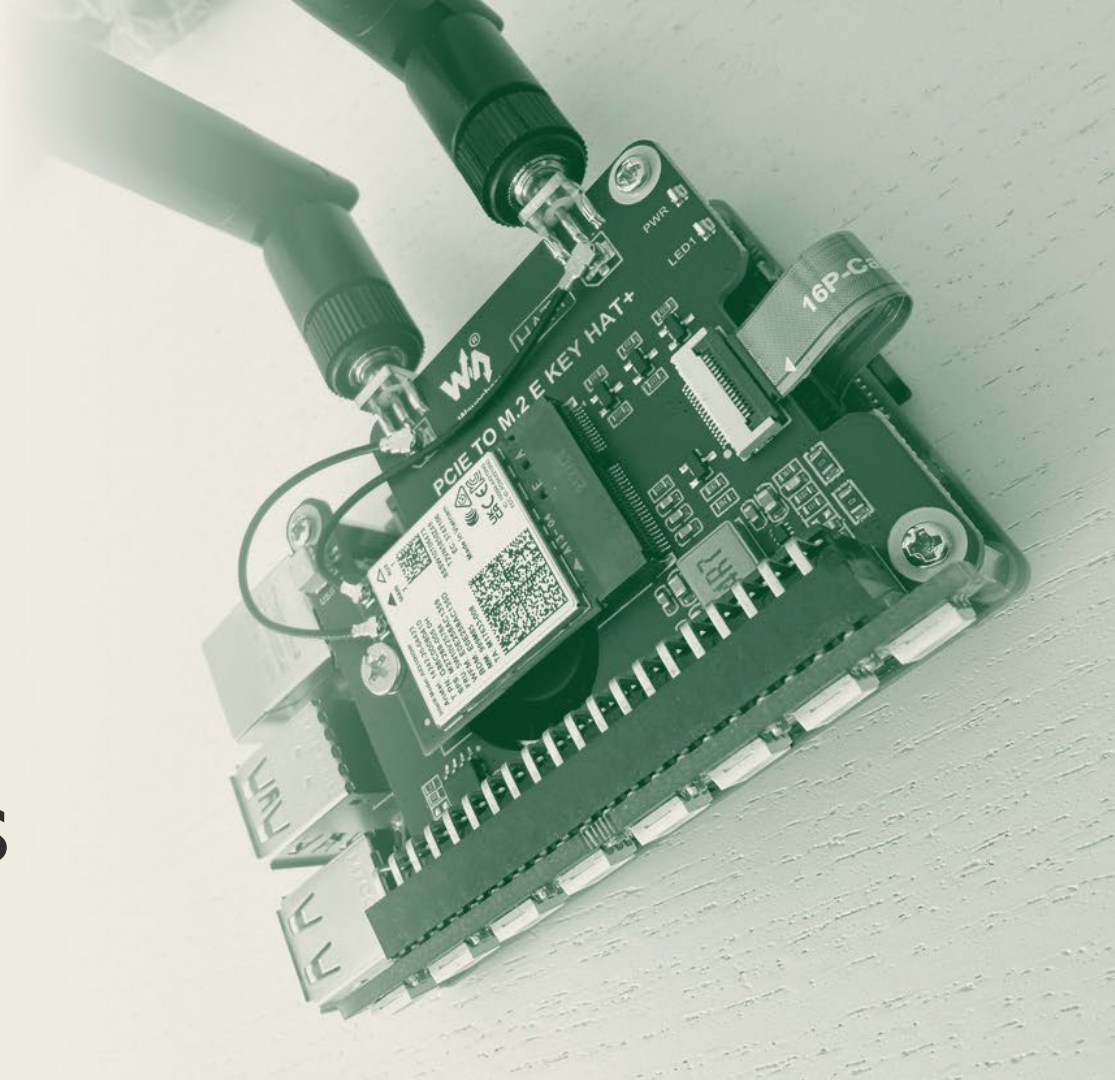
"may be required to disclose ... in response to a valid subpoena, court order, search warrant"

Opt-in, off by default.

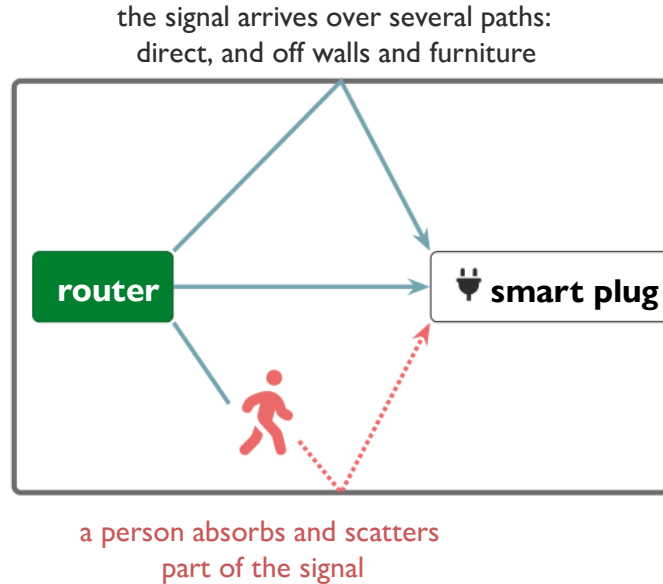
corporate.comcast.com, 10 Oct 2026; The Verge, TechCrunch, 18 Aug 2026; TechTimes, 19 Aug 2026; xfinity.com, 5 Oct 2026.

01

Wi-Fi channel measurements



Sensing principle: Channel State Information (CSI)



What is measured (CSI)

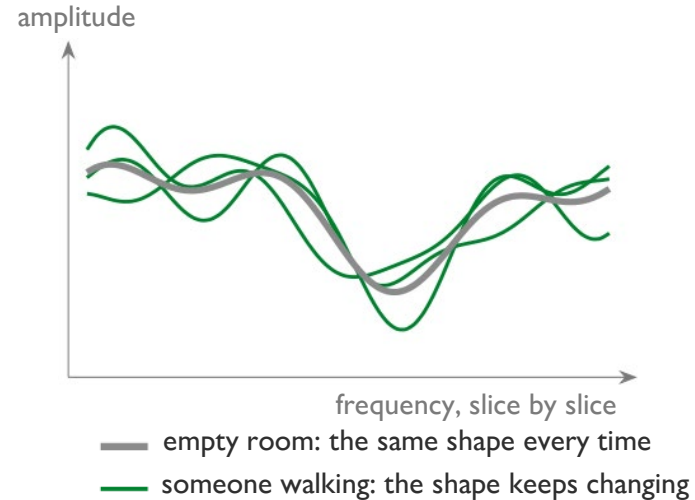
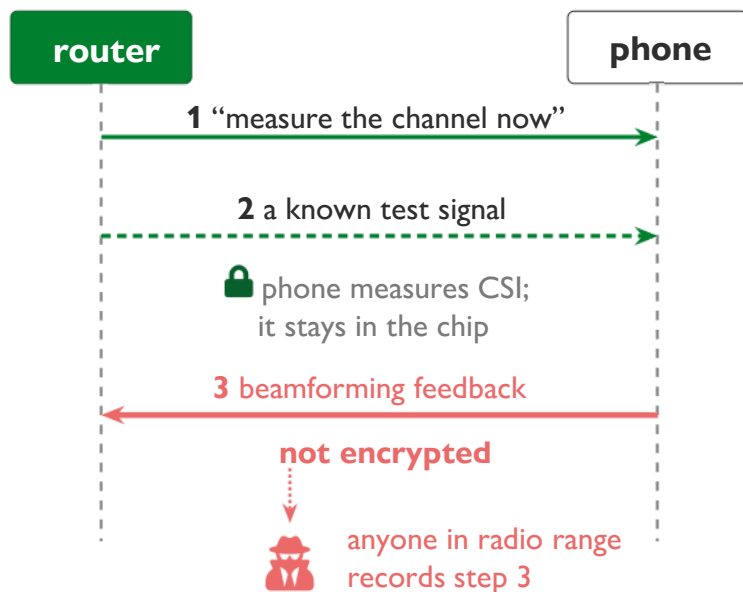


Illustration. Any Wi-Fi device can measure this: a plug, a lamp, a laptop.

Channel sounding and beamforming feedback



Example: one captured report (step 3)

From: a4:6b:40:...

the device's address, in clear text:
an identifier

To: the router

tells phones, laptops and TVs
apart

Format: Wi-Fi 6, 80 MHz,
4 router antennas, 2 streams

Angles ϕ , ψ for every group
of frequency slices: hundreds
to thousands of numbers

a compressed copy of the
channel: it changes when
someone moves

Sent up to several times per second, for each device.

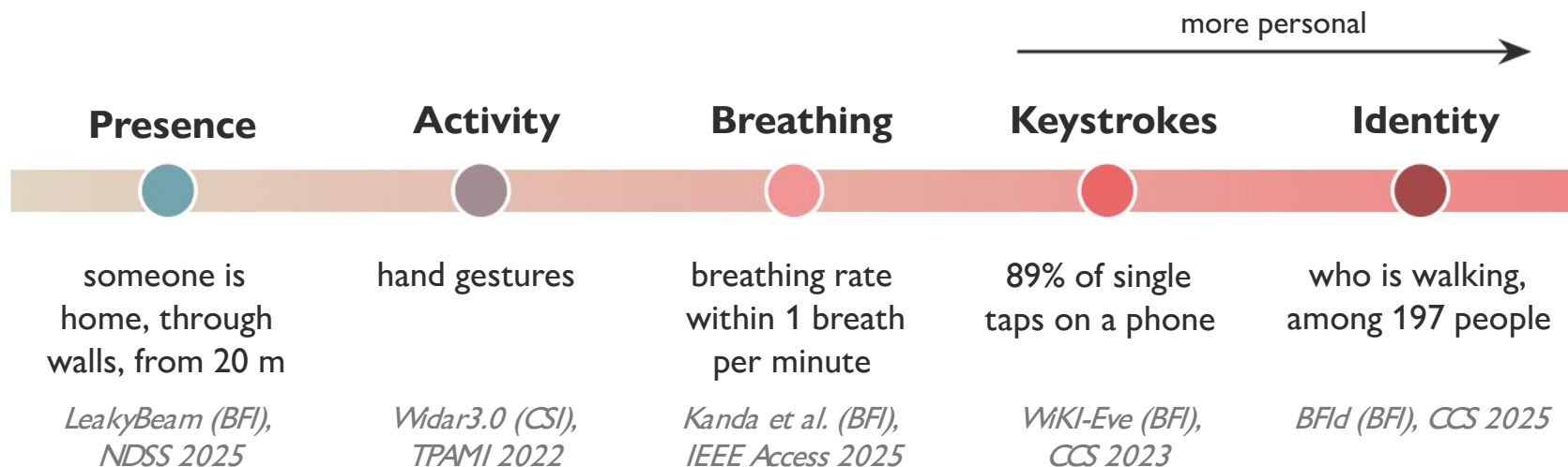
WPA2 and WPA3 encrypt data frames only. IEEE 802.11ac-2013 (Wi-Fi 5), IEEE 802.11ax-2021 (Wi-Fi 6).

02

Inference from
channel data



Inference levels: presence to identity



Four of the five use beamforming feedback that any nearby radio can capture. Most are controlled studies: few people, one building, a known layout.

Identification at scale (BFId, 2025)

The image shows a screenshot of the Karlsruhe Institute of Technology (KIT) website. The top navigation bar includes links for Home, Plain Language, Legals, Privacy Policy, Accessibility, Sitemap, Intranet, and KIT. The main content area features a press release titled "The Spy Who Came in from the WiFi: Beware of Radio Network Surveillance!" dated 069/2025. The press release states that new technology is able to infer the identity of individuals from WiFi signals. Below the press release, there is a news article from Futurism titled "Random Standard Wi-Fi Routers Can Scan Your Body to Identify Exactly Who You Are, Alarming New Research Finds". The article mentions that with this hardware making its way into millions of homes, the privacy concerns are severe. The article is by Joe Wilkins and was published on May 31, 2026. The URL for the article is <https://futurism.com/future-society/wifi-routers-scan-body-identify-research>.

KIT
Karlsruhe Institute of Technology

Home Plain Language Legals Privacy Policy Accessibility Sitemap Intranet KIT DE

KIT Topics Studies Research Innovation Career

Karlsruhe Institute of Technology > KIT > Media > Press Releases > Archive Press Releases https://www.kit.edu/kat/english/pi_2025_069_the-spy-who-came-in-from-the-wifi-beware-of-radio-network-surveillance.php

Press Release 069/2025

The Spy Who Came in from the WiFi: Beware of Radio Network Surveillance!

New Technology is Able to Infer the Identity of Individuals from WiFi Signals
Protective Measures

Random Standard Wi-Fi Routers Can Scan Your Body to Identify Exactly Who You Are, Alarming New Research Finds

"With this hardware making its way into millions of homes, the privacy concerns are severe."

By Joe Wilkins / Published May 31, 2026 9:00 AM EDT / Add Futurism

<https://futurism.com/future-society/wifi-routers-scan-body-identify-research>

197 people identified with almost 100% accuracy
KIT: it "could potentially be applied to **monitor protesters**".

KIT press release 069/2025 (ScienceDaily, 12 Aug 2026); Futurism, 31 May 2026; Todt, Marsbach, Strufe, ACM CCS 2025.

Trends or privacy concern? Both?

Why does every celebrity have wired headphones in their bag?



Barbra Wyre Updates ✨
@BarbraWyre

Hate being caught with a tinfoil hat on but there's a reason why celebs wear wired headphones and not AirPods/bluetooth.

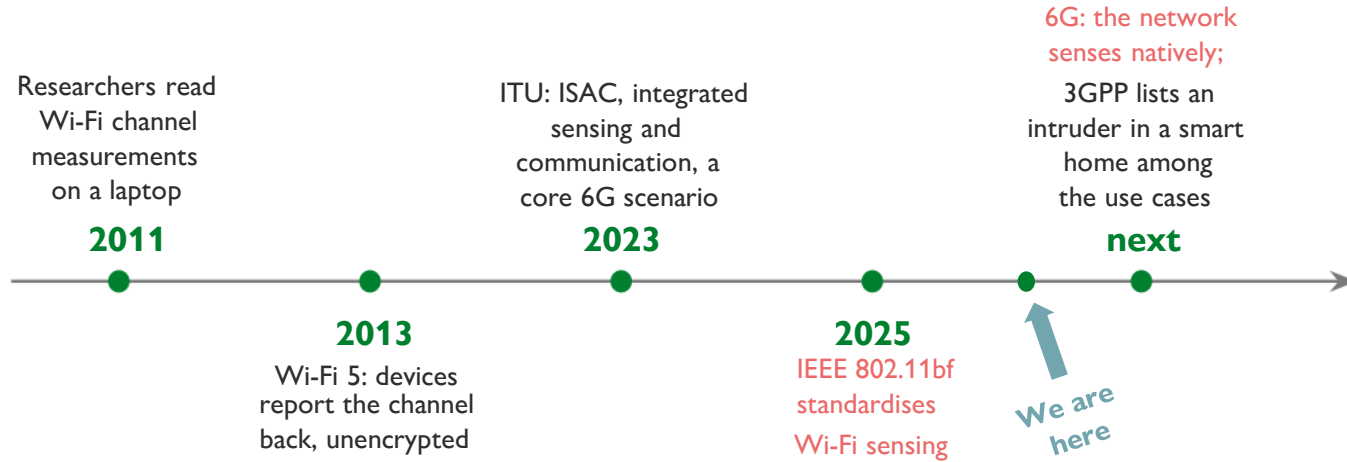


03

Threat model:
three observers



How we got here? ISAC and 802.11bf



ISAC: one radio, one waveform, two jobs. Sensing stops being a feature of the router and becomes a function of the network.

ISAC: Integrated Sensing and Communication

Halperin et al., CSI Tool, SIGCOMM CCR 2011; IEEE 802.11ac-2013; ITU-R M.2160 (IMT-2030), 2023; IEEE 802.11bf-2025; 3GPP Rel-19 channel models (2025), Rel-20 studies, TR 22.837.

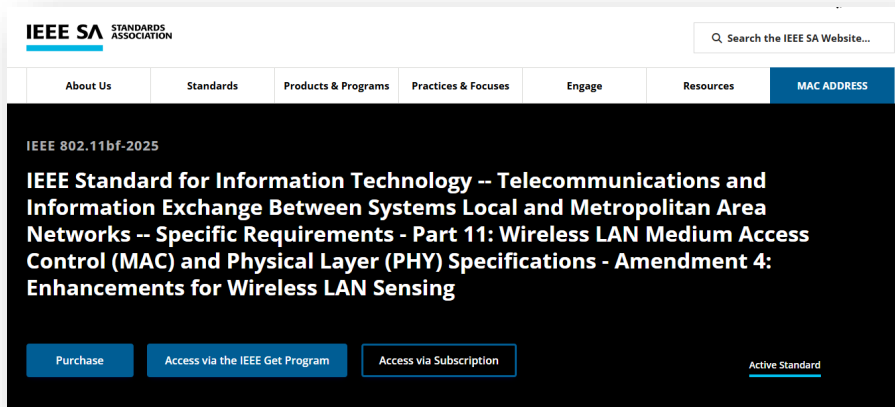
IEEE 802.11bf: sensing as a router function

 The router decides **whom** to measure, and **how often**.

 The router **receives** every device's report.

 A privacy fix was proposed and **rejected**:

- “sensing privacy” never defined
- the leak “is not unique to sensing”
- “may make WLAN sensing look very bad”
- left to 802.11bi: MAC layer, not signal



The screenshot shows the IEEE SA Standards Association website. The top navigation bar includes links for About Us, Standards, Products & Programs, Practices & Focuses, Engage, Resources, and MAC ADDRESS. A search bar is located in the top right corner. The main content area displays the title of the IEEE 802.11bf-2025 standard: "IEEE Standard for Information Technology -- Telecommunications and Information Exchange Between Systems Local and Metropolitan Area Networks -- Specific Requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications - Amendment 4: Enhancements for Wireless LAN Sensing". Below the title, there are three buttons: "Purchase", "Access via the IEEE Get Program", and "Access via Subscription". A link labeled "Active Standard" is also present.

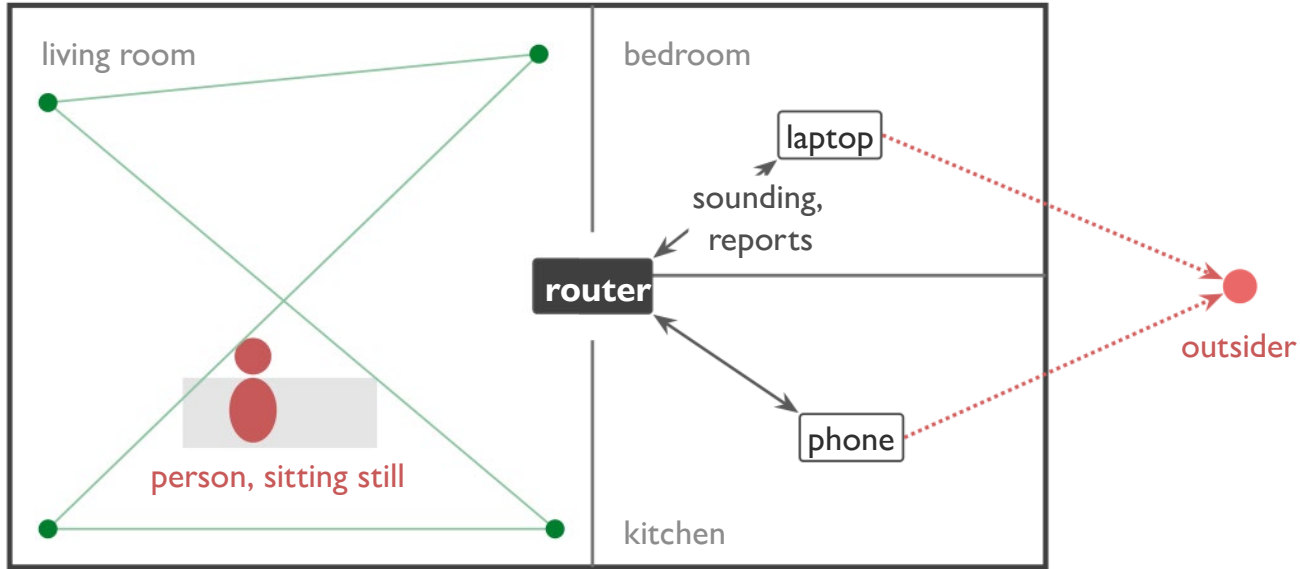
WiFi Sensing and the Privacy Fix Its Committee Couldn't Agree to Make

A new IEEE standard makes WiFi body sensing a product. The privacy fix for the sensed body was proposed and never made; it secured itself instead.

<https://pascalpiron.substack.com/p/wifi-sensing-and-the-privacy-fix>

Quotes: IEEE 802.11-23/1109r0 and 11-23/0782r1 (2023), as reported by P. Piron, June 2026.

Threat model: household, provider, outsider (observers)



● **Household:** own devices as a mesh

■ **Router:** measures all

● **Outsider:** listens

Provider-side sensing in practice



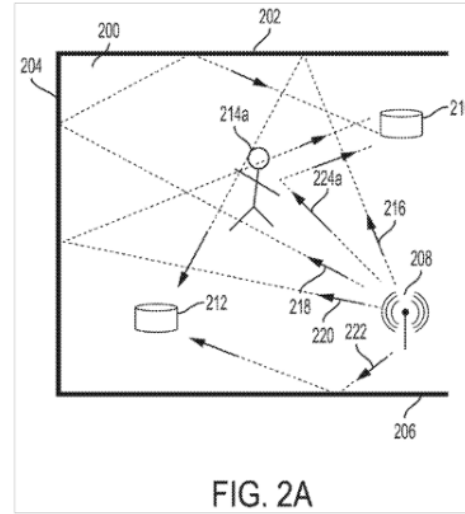
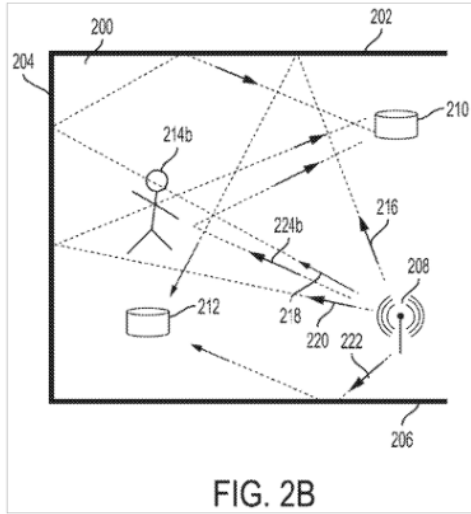
So macht ein Hersteller einen WLAN-Router zum Bewegungsmelder

Bewegungen verändern das WLAN-Signal. So kann ein einfacher Router erkennen, ob sich eine Person unbefugt durch einen Raum bewegt. Auch die Telekom bietet diese Sicherheitsfunktion teilweise schon an.

Telekom: Speedport 7, opt-in (t3n, Aug 2026)

-  Plume, behind many providers: keeps a **motion history**, shares it with the provider.
-  Rogers: **7 days** of motion history in the app.
-  Telekom: identity “**not recognizable**”. **However**, ... KIT: 197 people identified.

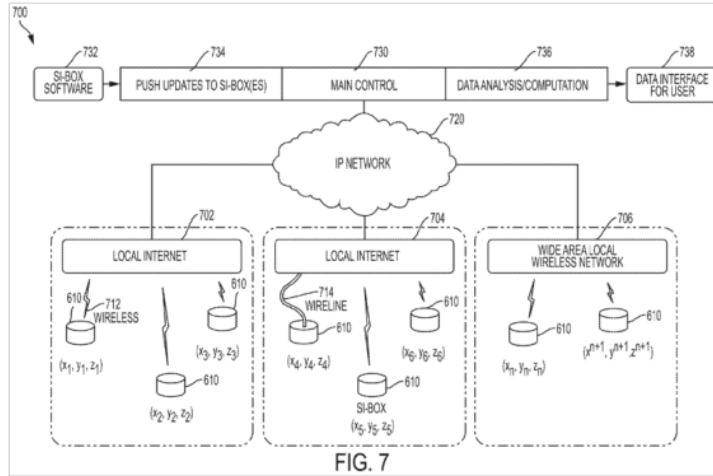
Cognitive Systems: how the sensing works



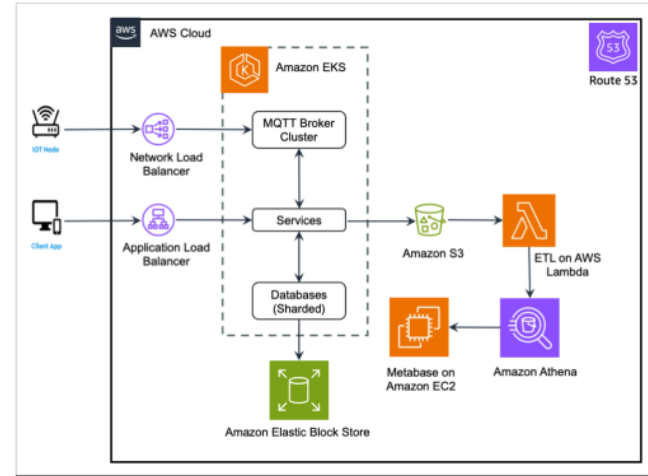
One transmitter (208), two listening devices (210, 212). The person moves (214a to 214b); the reflected paths change; the listeners see the change in every frame.

Cognitive Systems Corp., US patent 9,523,760, "Detecting motion based on repeated wireless transmissions", FIG. 2A and 2B (filed 15 Apr 2016, granted 20 Dec 2016).

Cognitive Systems: from the home to the cloud



The patent (2016): sensing boxes in each home report over the Internet to a main control and analysis service.



The deployment (2023): the gateway reports over MQTT; events are stored in S3 and analysed, per AWS region.

Left: US 9,523,760, FIG. 7. Right: Cognitive Systems Corp. on AWS, "Amazon EKS journey: Wi-Fi sensing technology", Figure 1, AWS Containers blog, 22 Nov 2023.

Observing (encrypted) traffic patterns has always been the case

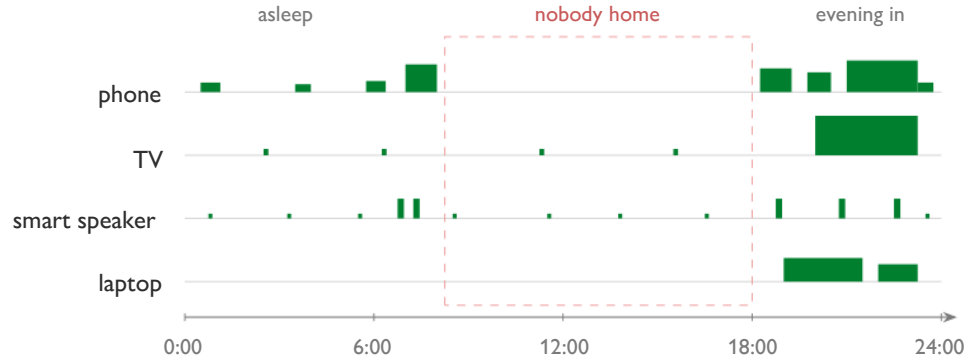


*Illustration. Apthorpe, Reisman, Feamster, "A Smart Home is No Castle", 2017 (ISP view);
Acar et al., "Peek-a-Boo", ACM WiSec 2020 (near the home).*

Encryption hides *what*. The provider sees *which device, when, how much*.

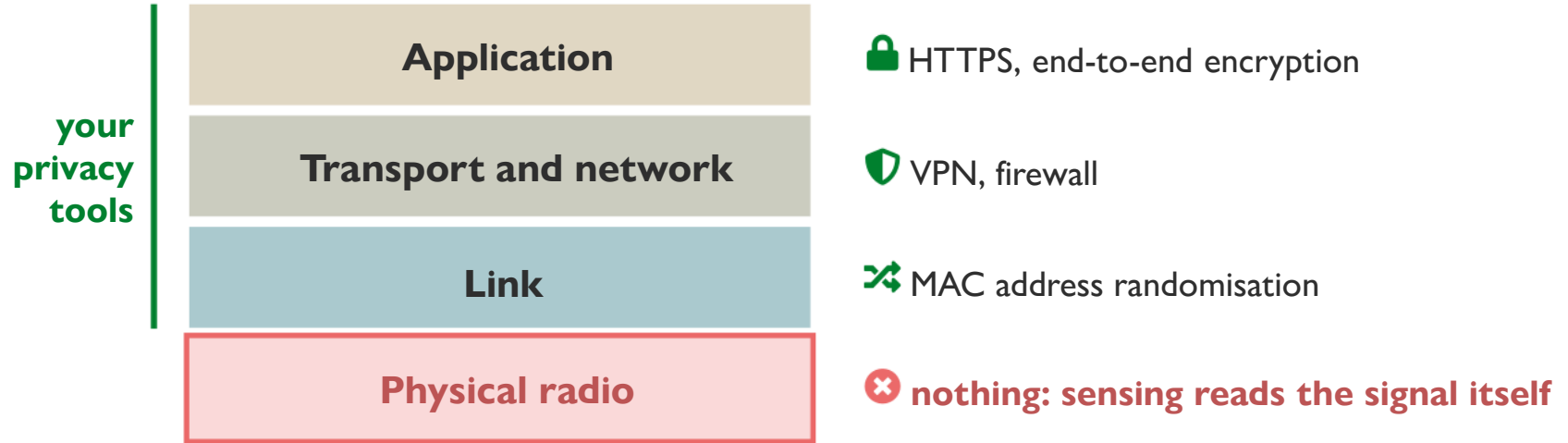
Enough for sleep, absence and routines (shown in 2017).

Two channels, one provider:
motion from the radio, routine from the traffic.

And we also do it to observe mental health

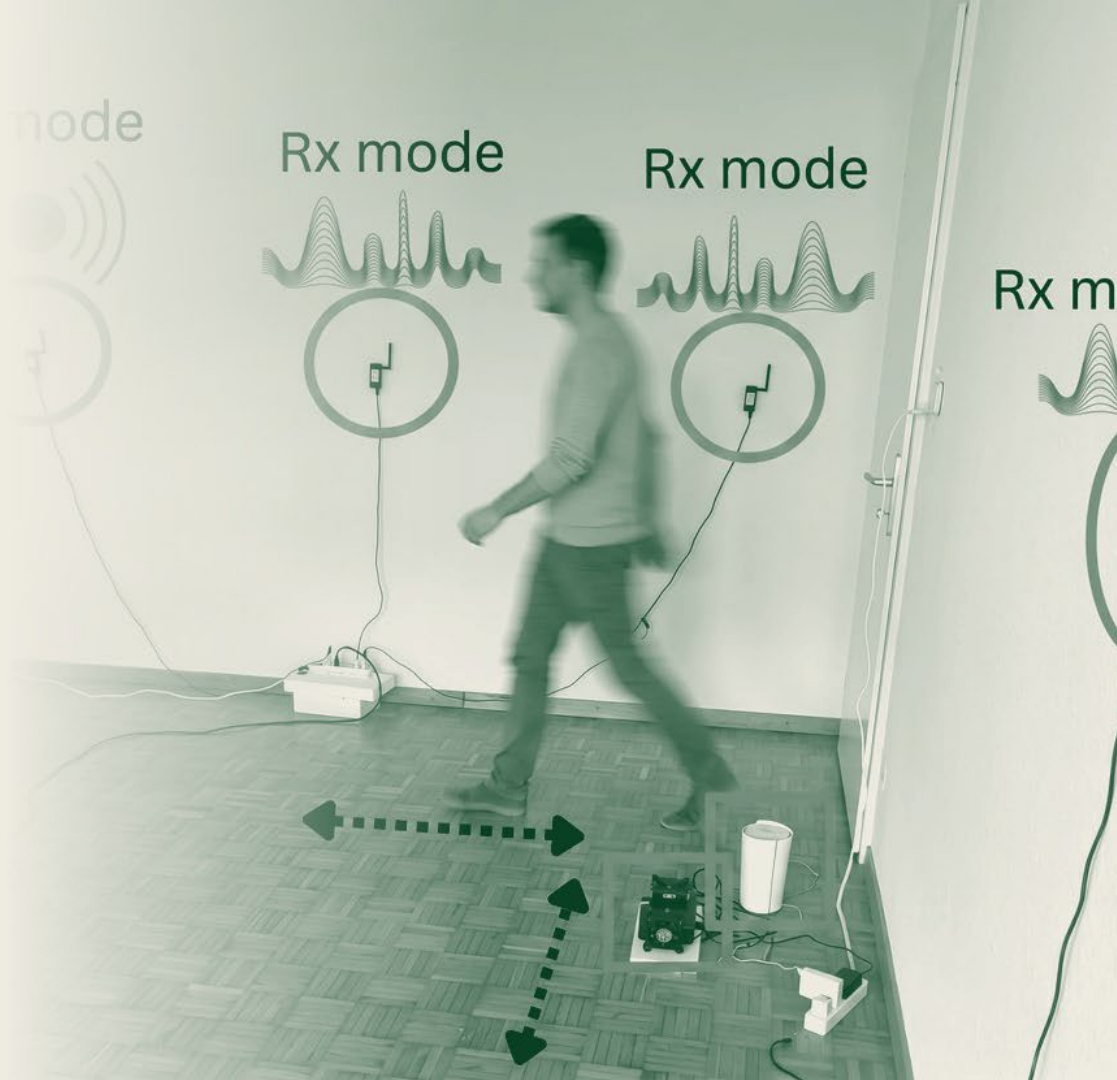


Limits of existing privacy protections



04

Evidence from
our testbed



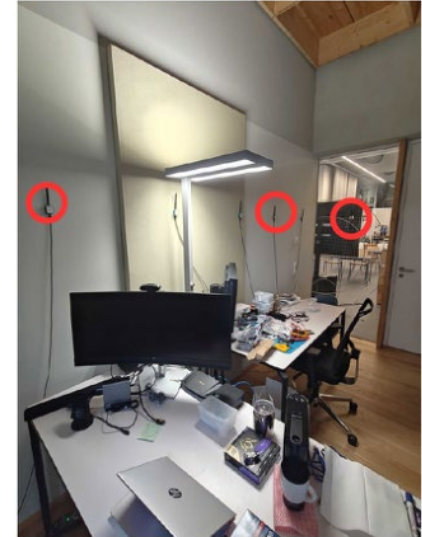
Testbeds



Living room, 3.3×6.1 m



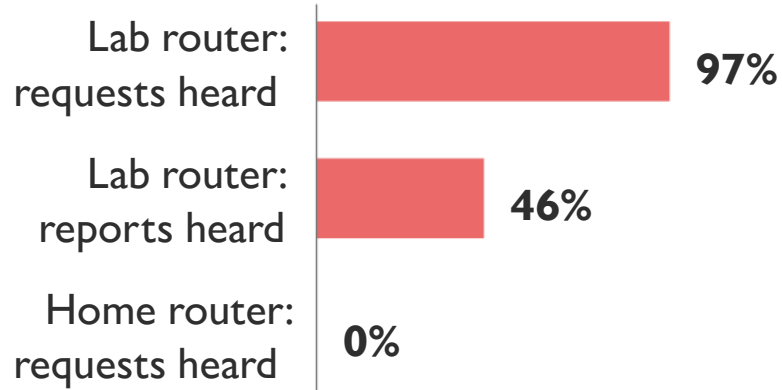
Robotics lab, 7.0×4.4 m



Office, 2.9×4.4 m

Red circles: our ESP32 boards, the kind of chip in smart plugs and lamps. Photos: K. Khamaisi; "OpenCSI", IEEE LCN 2026.

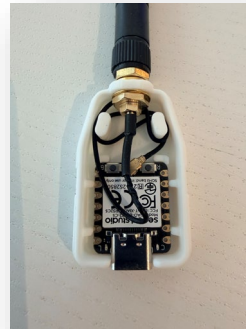
Passive capture with a low-cost receiver



sent in the wide Wi-Fi 6 format

📶 A low-cost ESP32-C5 board, compared with a full-width reference receiver.

📍 **3 of 4** routers we tried were audible. It misses only frames sent in the wide Wi-Fi 6 format.

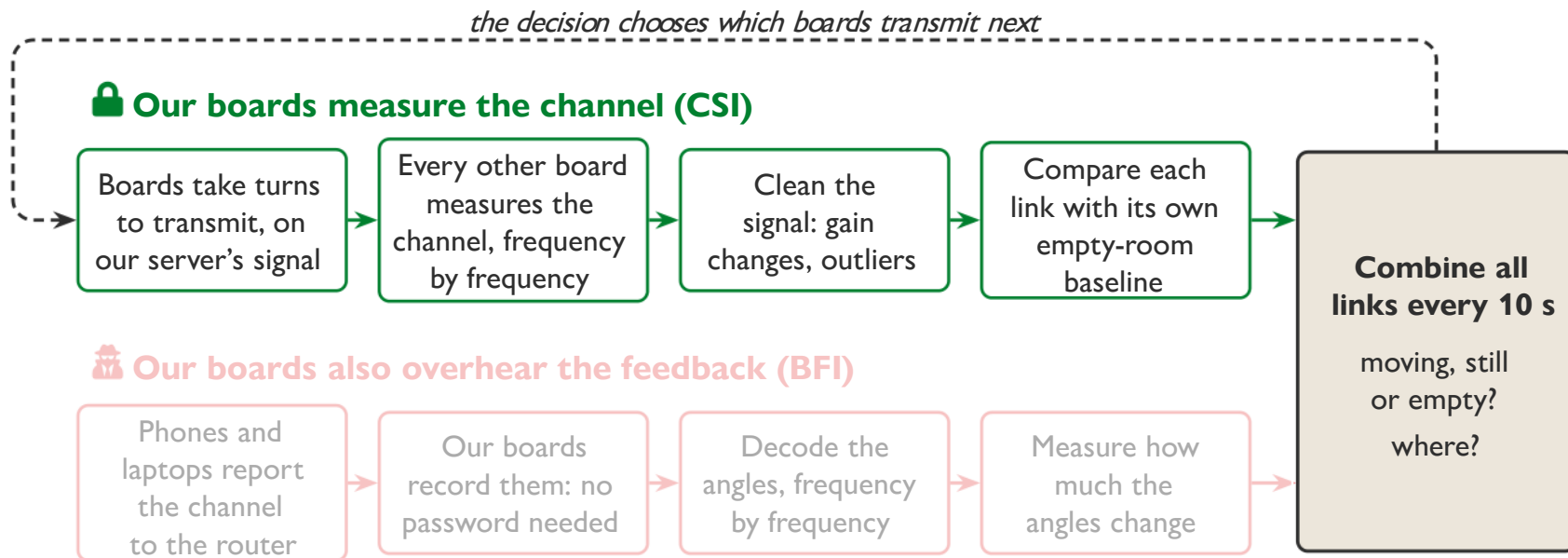


The deployed system: live view



Our dashboard for the apartment: the boards and the links between them, the occupancy map, and the presence decision, from the Wi-Fi channel alone. Screenshot from an earlier stage with 9 boards; the system now runs 20 boards and 380 links.

Sensing pipeline



20 boards, 380 links; a decision every 10 s, 10 to 20 s after a movement. ESP32-C5, the chip family of many smart plugs.

Results: occupied apartment

What works

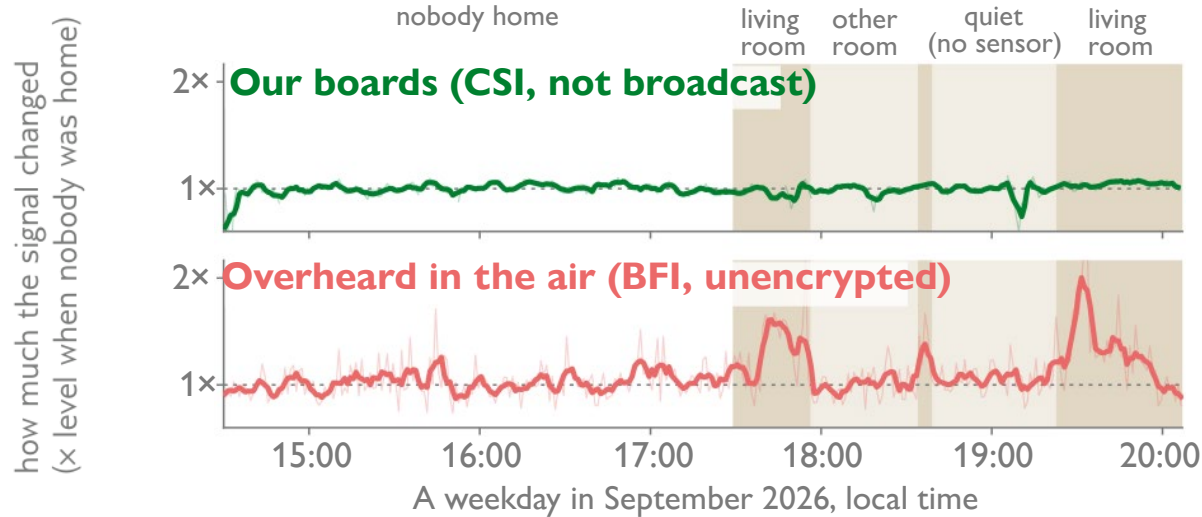
-  Someone is moving
-  Nearest board: **33%** (chance 5%), *if it transmits*
-  Flat empty $\approx$ **2 min** after leaving

What does not

-  Sitting still looks like an empty room
-  **7 of 30:** “empty” while still home
-  Nearest board silent: **0%**

Exits checked against the home's motion sensors; location on a labelled walk.

Case study: CSI and BFI over one afternoon



Overheard feedback showed someone in the room; our CSI summary barely moved. One afternoon: a case, not a rate.

Motion is (relatively)
easy.

Differentiating stillness
from emptiness is not
straightforward.

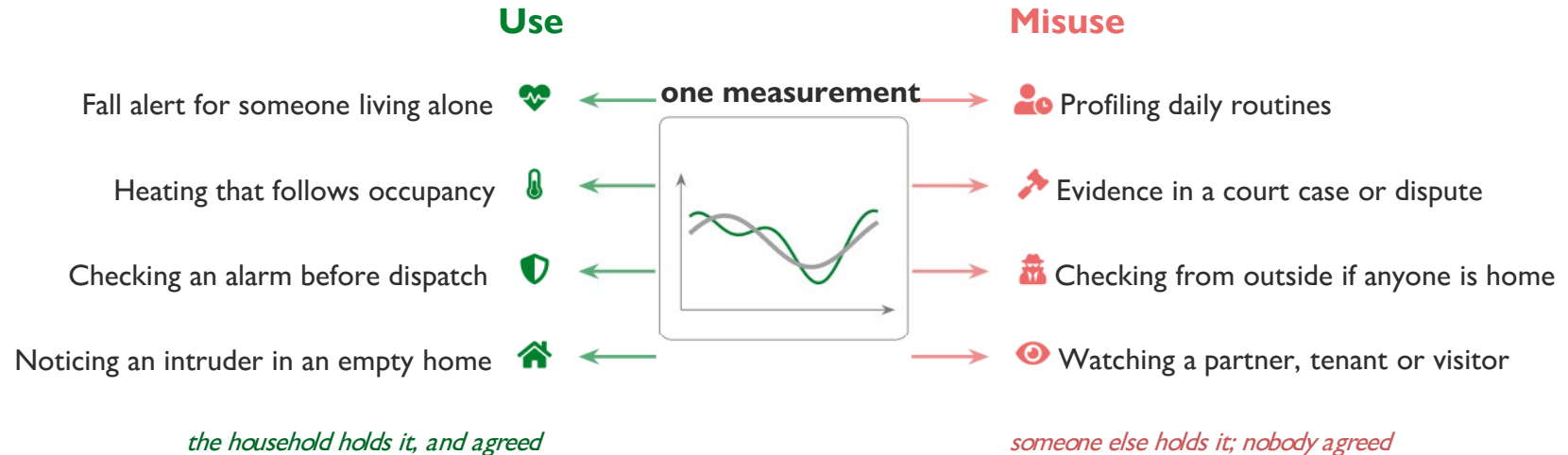


05

Regulation and open questions

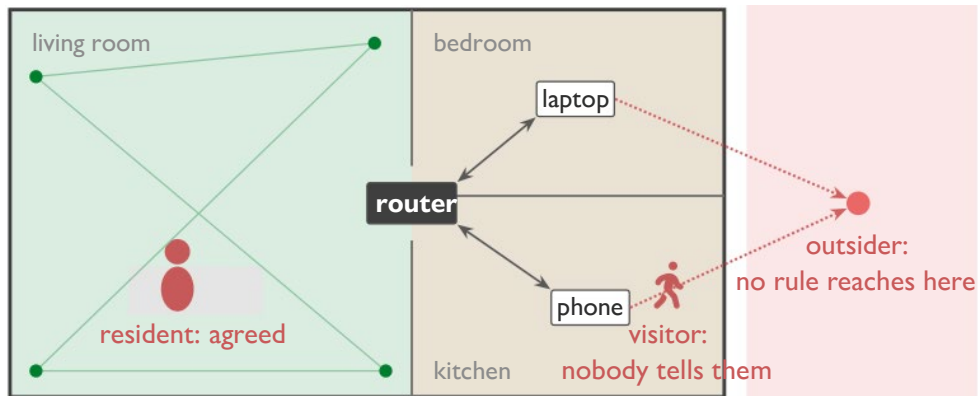


Uses and misuses



The measurement is the same for both **use** and **misuse**
The key questions are **who holds the data**, and **who agreed**.

Legal coverage: household, provider, outsider



■ **Household:** own devices, own consent. Breathing or gait: explicit consent.

■ **Provider:** data-protection law. EU: consent, arguably. CH: inform, allow refusal.

■ **Outsider, visitors:** no clear rule. No authority has addressed Wi-Fi sensing yet.

GDPR Art. 9; ePrivacy Dir. 5(3), EDPB 2/2023 § 34; AI Act Annex III; FADP Art. 5, 6; Telecom Act Art. 45c, 50; Federal Council, 20 May 2026. Not legal advice.

Kyllo v. United States (2001)



“In the home ... all details are intimate details.”

A thermal camera on a home is a search: a **warrant** is needed, **“at least where the technology is not in general public use”**.

Wi-Fi sensing ships in millions of routers. General public use?

Kyllo v. United States, 533 U.S. 27 (2001); binds the state, not companies. Image: NASA thermograph of Cleveland homes, 1977 (US National Archives, public domain), not the case evidence.

Discussion: computer science × law

 Is breathing, sensed by radio, **health data**, even when the inference is wrong?

 Who **consents for visitors**, who are neither subscriber nor user?

 Should the Wi-Fi standard have to **protect the feedback**?

 Who **certifies what an observer cannot see**, and how?

Questions?



University of St.Gallen

Bruno Rodrigues
bruno.rodrigues@unisg.ch



***"From insight
to impact"***

Backup



References

- IEEE Std 802.11bf-2025, Enhancements for Wireless LAN Sensing. IEEE, 2025.
- D. Halperin et al., “Tool Release: Gathering 802.11n Traces with Channel State Information”, ACM SIGCOMM CCR 41(1), 2011.
- ITU-R Recommendation M.2160-0, Framework and overall objectives of IMT for 2030 and beyond, November 2023.
- 3GPP TR 22.837, Feasibility study on integrated sensing and communication (Release 19); Release 19 ISAC channel modelling and Release 20 sensing studies.
- R. Xiao et al., “Lend Me Your Beam: Privacy Implications of Plaintext Beamforming Feedback in WiFi” (LeakyBeam), NDSS 2025.
- Y. Zhang et al., “Widar3.0: Zero-Effort Cross-Domain Gesture Recognition with Wi-Fi”, IEEE TPAMI 44(11), 2022.
- T. Kanda et al., “Beamforming Feedback-Based Respiration and Heart Rate Estimation Toward Firmware-Agnostic WiFi Sensing”, IEEE Access 13, 2025.
- J. Hu et al., “Password-Stealing without Hacking: Wi-Fi Enabled Practical Keystroke Eavesdropping” (WiKI-Eve), ACM CCS 2023.
- J. Todt, F. Morsbach, T. Strufe, “BFId: Identity Inference Attacks Utilizing Beamforming Feedback Information”, ACM CCS 2025.
- C. Wu et al., “Enabling Ubiquitous WiFi Sensing with Beamforming Reports”, ACM SIGCOMM 2023.
- M. Seif et al., “Protecting Human Activity Signatures in Compressed IEEE 802.11 CSI Feedback”, IEEE DySPAN 2026.
- Sensing Group HSG, “One-Shot Identification from WiFi Beamforming Feedback Information”, unpublished manuscript, 2026.

References (continued)

- Xfinity Wi-Fi Motion support page: August 2026 wording (“without further notice to you”) as quoted in TechTimes, 19 Aug 2026; revised wording (“may be required to disclose ... in response to a valid subpoena, court order, search warrant or other lawful legal process”) at xfinity.com/support/articles/wifi-motion-faqs, accessed 5 Oct 2026; TechCrunch, 18 Aug 2026; The Register, “Comcast gives its Wi-Fi motion detector a security makeover”, 19 Aug 2026 (launched 2025); TidBITS, 2 Sep 2026; B. Schneider, Crypto-Gram, 15 Sep 2026.
- KIT press release “Ordinary WiFi can now identify you with near-perfect accuracy”, via ScienceDaily, 12 Aug 2026.
- IEEE 802.11-23/0782r1; 802.11-23/1109r0, LB272 privacy comments, 29 Jun 2023 (“REJECTED. The definition of sensing privacy is not clear”); P. Piron, Substack, 11 Jun 2026.
- ADT Inc., Form 8-K, 24 Feb 2026 (acquisition of Origin Wireless, d/b/a Origin AI).
- Comcast, Xfinity Privacy Policy, effective 23 Apr 2026; Rogers, “Activating WiFi Motion” support page; Telekom, “Wi-Fi-Sensing einfach erklärt”; Telekom hilft Labor, field test call (May 2026); Arris Enterprises, US 2014/0279047 A1, “Enhancing targeted advertising in a home network gateway device”.
- N. Bölling, “So macht ein Hersteller einen WLAN-Router zum Bewegungsmelder”, t3n, 21 Aug 2026 (Telekom Speedport 7); Plume Customer Privacy Policy, last updated 1 Jul 2026, plume.com/legal/privacy.
- MacRumors, “Linksys Introduces ‘Linksys Aware’ Service for Sensing Motion Using Mesh Wi-Fi”, 8 Oct 2019; S. Kaminsky, Kaspersky blog, 17 Jul 2025 (service discontinued mid-2024).
- Wi-Fi NOW, “Breakthrough in Wi-Fi sensing: 37 service providers deploy Cognitive’s Wi-Fi Motion”, 19 Feb 2021.
- Verizon press release, “Verizon launches new tech to monitor activity on home WiFi” (Home Awareness, Origin), 10 Oct 2022.
- J. Wilkins, “Random Standard Wi-Fi Routers Can Scan Your Body to Identify Exactly Who You Are, Alarming New Research Finds”, Futurism, 31 May 2026.
- EU: GDPR (EU) 2016/679, Art. 2, 9, 25; ePrivacy Directive 2002/58/EC, Art. 5(3); EDPB Guidelines 2/2023 v2.0 (7 Oct 2024), § 34; ePrivacy Regulation proposal withdrawn, OJ C/2025/5423; AI Act (EU) 2024/1689, Art. 5(1)(f), Annex III, amended by (EU) 2026/1744; Delegated Reg. (EU) 2022/30, Art. 1(2), amended by 2023/2444, repealed from 11 Dec 2027 by Delegated Reg. (EU) 2026/339; Data Act (EU) 2023/2854, Art. 50; Cyber Resilience Act (EU) 2024/2847, Art. 71.
- Switzerland: FADP SR 235.1, Art. 2, 5, 6, 7, 22; Telecommunications Act SR 784.10, Art. 43, 45c; Criminal Code SR 311.0, Art. 179quater; Federal Council press release, 12 Feb 2025; FDPIC, 8 May 2025.

References (added October 2026)

- *Kyllo v. United States*, 533 U.S. 27 (2001), opinion of the Court (Scalia, J.) incl. footnote 3; dissent (Stevens, J.).
- K. Khamaisi, S. Sigg, B. Rodrigues, “OpenCSI: Self-Calibration Layer for Heterogeneous Mesh Wireless Sensor Networks”, IEEE LCN 2026 (testbed photos by K. Khamaisi).
- Ring, “Community Requests” (with Axon), Ring and Axon blogs, Sep 2025; CNN, “Amazon’s Ring cancels Flock partnership”, 13 Feb 2026; Sen. E. Markey, letter to Amazon on Ring facial recognition, 11 Feb 2026.
- FCC, Verizon Wireless consent decree (unique identifier headers), 7 Mar 2016; FCC forfeiture orders on carriers’ location data, Apr 2024; US Supreme Court ruling upholding the FCC, 4 Jun 2026, as reported by The Hill.
- Switzerland: Telecommunications Act SR 784.10, Art. 50 (unauthorised use of received information); Federal Council answer to Interpellation 26.3414 (AI regulation), 20 May 2026.
- Cognitive Systems Corp.: US patent 9,523,760, “Detecting motion based on repeated wireless transmissions” (filed 15 Apr 2016); Wi-Fi NOW, “37 service providers deploy Cognitive’s Wi-Fi Motion”, 19 Feb 2021; Cognitive Systems and MaxLinear partnership, IoT Now, 14 Nov 2022; Cognitive Systems, “How Cognitive scales Wi-Fi sensing with cloud infrastructure”, 15 Jun 2025, and “More options with Wi-Fi sensing for client devices”, 15 Mar 2024; TidBITS, “Comcast turns Wi-Fi gateways into motion detectors”, 2 Sep 2026.
- Cover photo: Ahmet Yükses, Unsplash; section 03 photo: Chelaxy Designs, Unsplash (Unsplash License). Other section photos and the dashboard: our testbeds (Sensing Group; K. Khamaisi).
- Our measurements: home testbed, September 2026 (CSI summary and overheard beamforming feedback, labels from motion sensors and occupant notes); pipeline as documented in the project’s information-flow map.